

Who needs flow anyway?

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with Larry McLerran

[[hep-ph/0101133](#) and work in progress]

Scaling relations

Dimensional arguments:

$$\frac{dN}{dy dp_t^2} \sim \sigma \times f\left(\frac{p_t}{p_{\text{scaling}}}\right)$$

f : one universal function for charged particles, independent of centrality

σ : scaling in absolute normalization (y-axis)

p_{scaling} : scaling of the transverse momentum (x-axis)

For a color-glass-condensate (CGC), the only degrees of freedom left are:

- the transverse area (σ)
- the saturation momentum Q_s (p_{scaling})
- scaling function f

[Krasnitz and Venugopalan, PRL 86 (2001) 1717]

→ scaling should work for $p_t < Q_s$

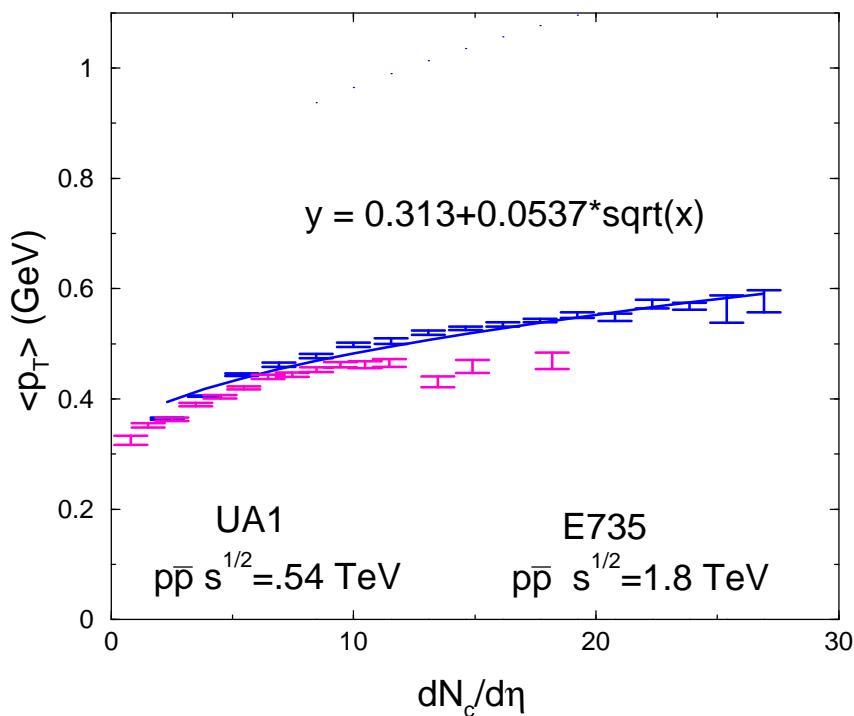
Scaling relation for the mean transverse momentum

Integrate over p_t :

$$\frac{1}{\sigma} \cdot \frac{dN}{dy} \sim \int_0^\infty f\left(\frac{p_t}{p_{\text{scaling}}}\right) dp_t^2$$

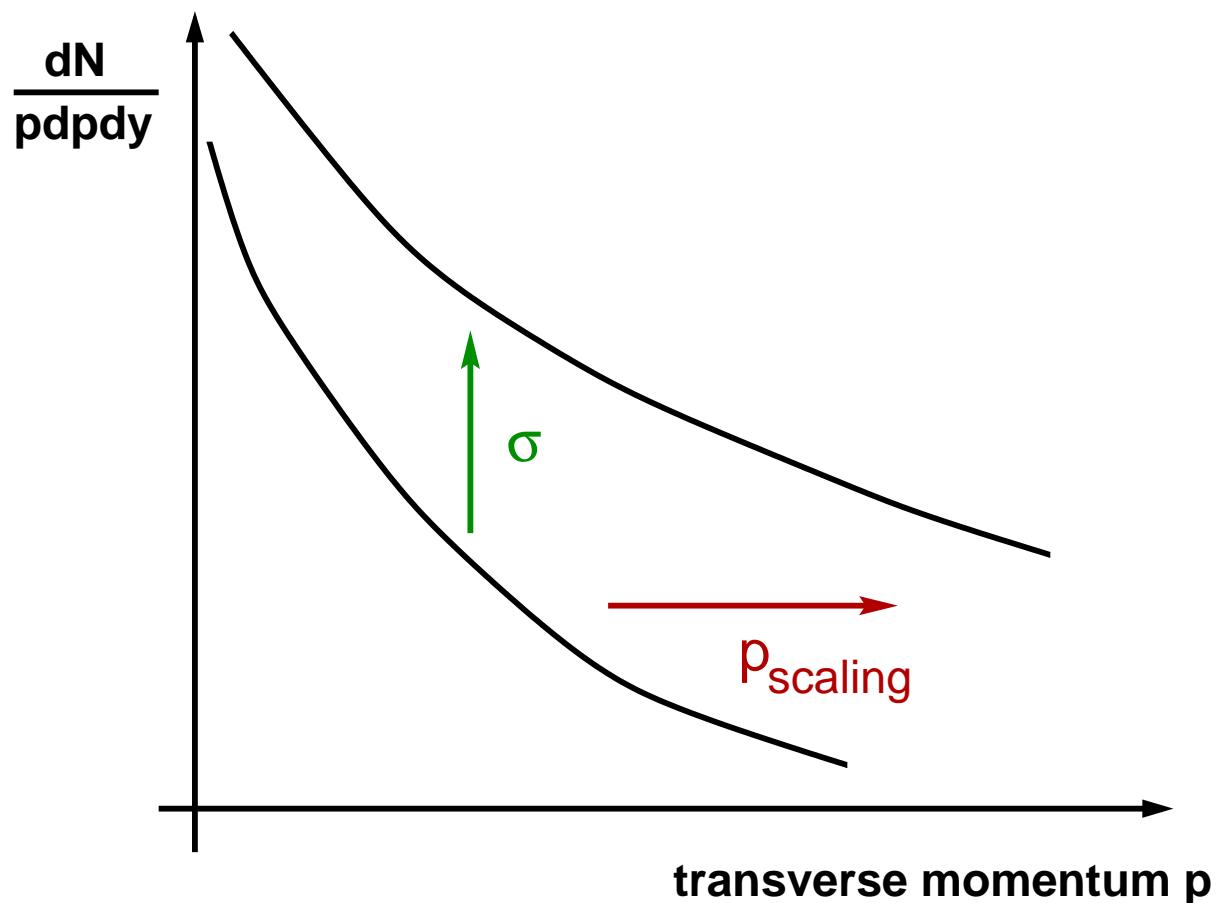
$$\frac{1}{\sigma} \cdot \frac{dN}{dy} \sim \# \cdot p_{\text{scaling}}^2 \sim \langle p_t \rangle^2$$

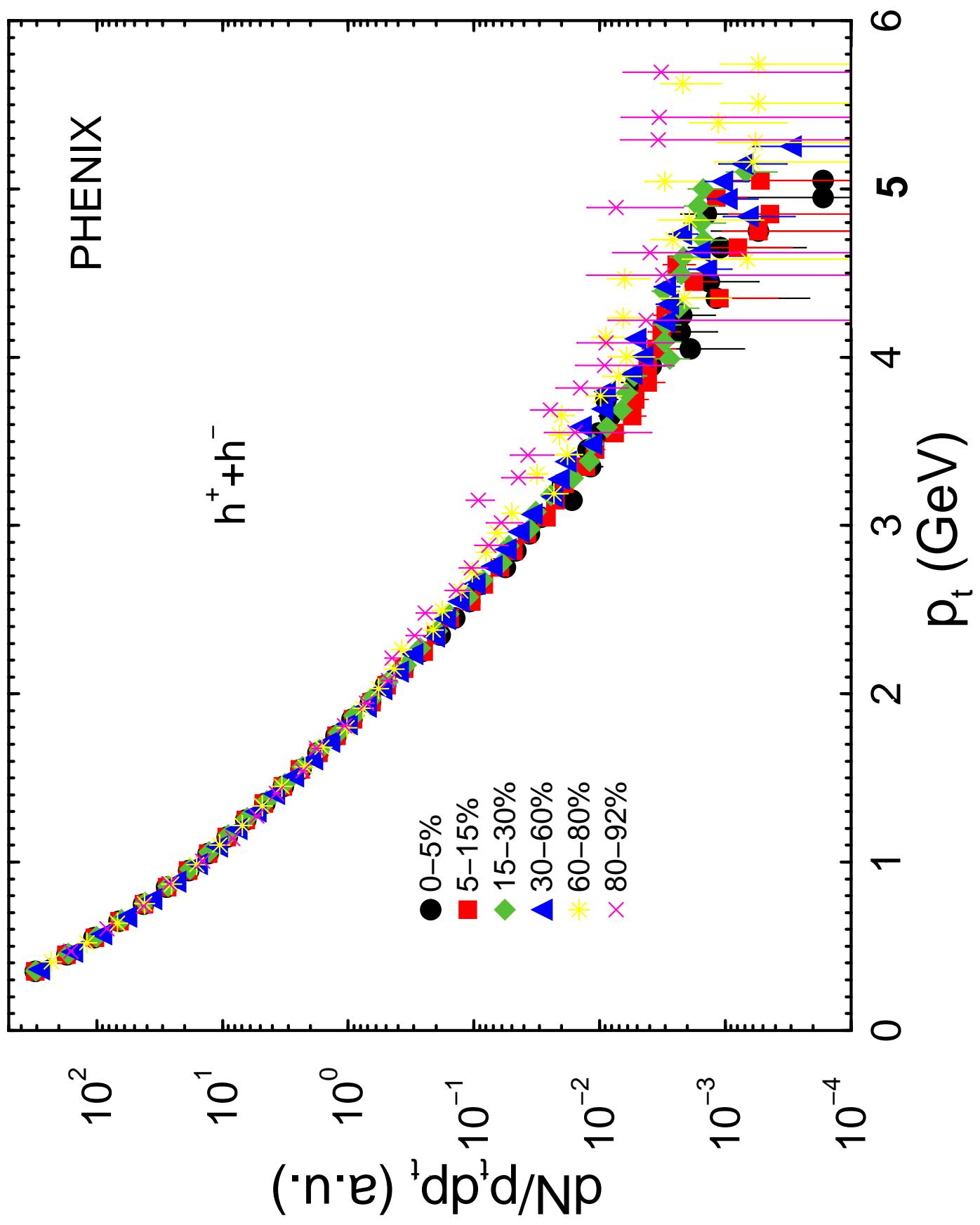
For pp: $\langle p_t \rangle \sim \sqrt{dN_c/d\eta}$



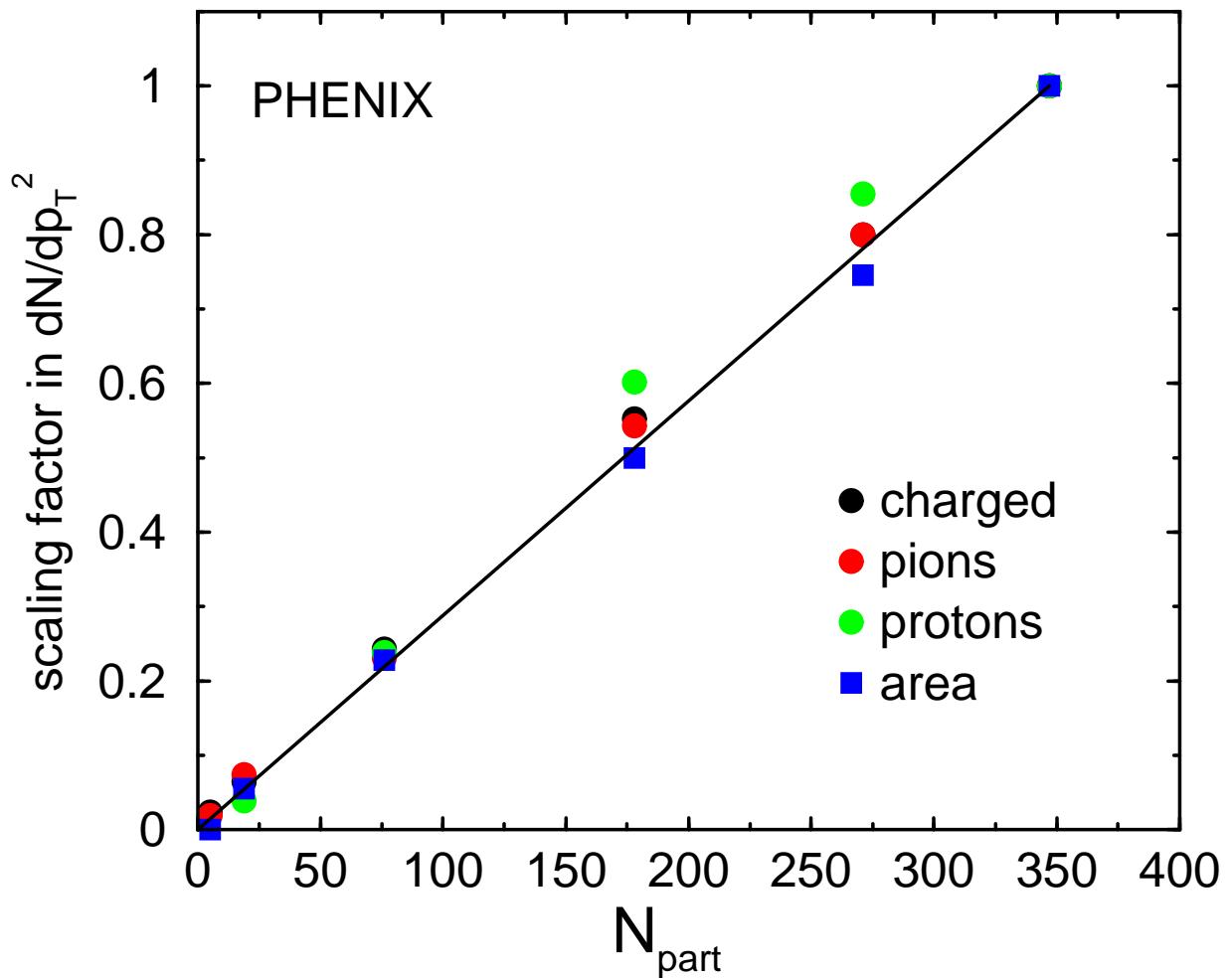
Charged particle spectra at RHIC

check universality of scaling function f by rescaling of $dN/dy dp_t^2$ and p_t , so that data of different centralities are on top of each other:





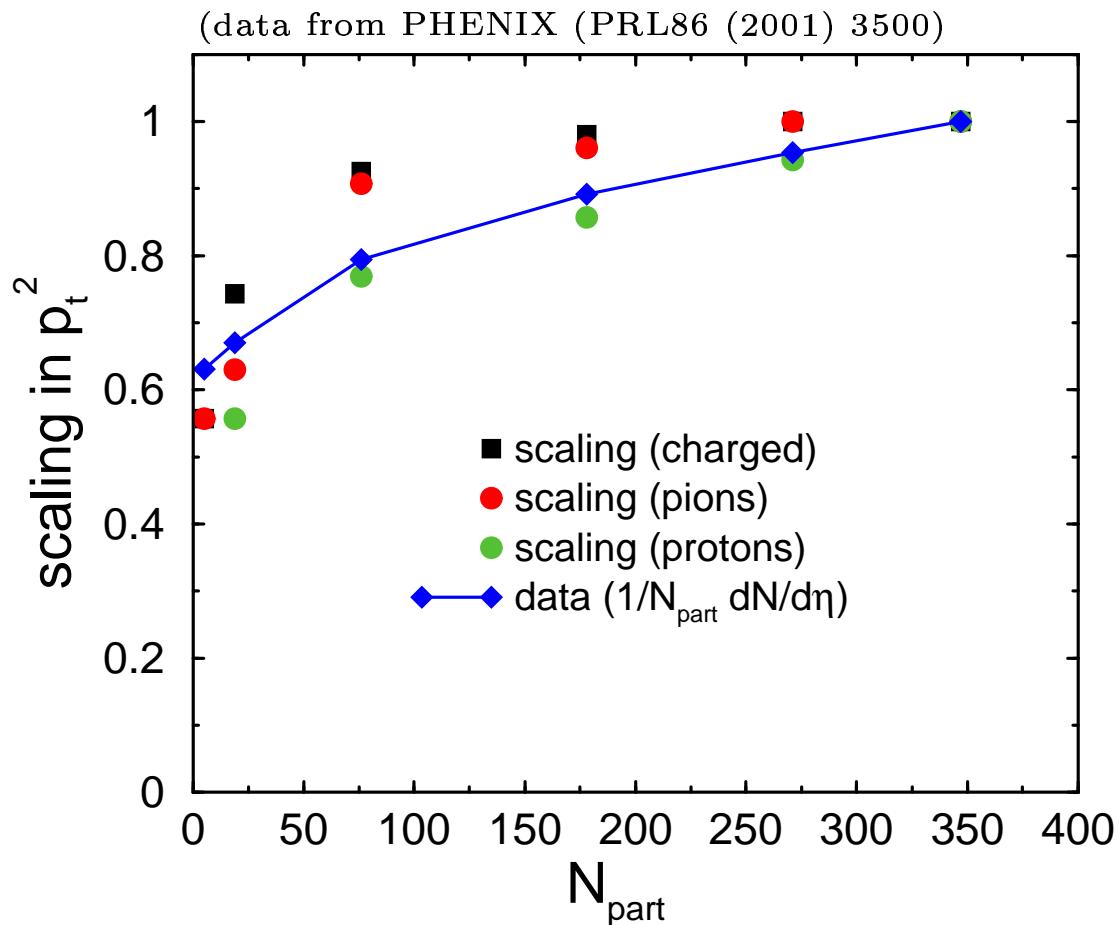
Scaling in absolute normalization



$$\sigma(\text{fit}) \sim N_{\text{part}} \sim \text{transverse area}$$

(N_{part} from PHENIX (PRL86 (2001) 3500), transverse area from overlap of two hard spheres using impact parameters from Nardi and Kharzeev, PLB507 (2001) 121)

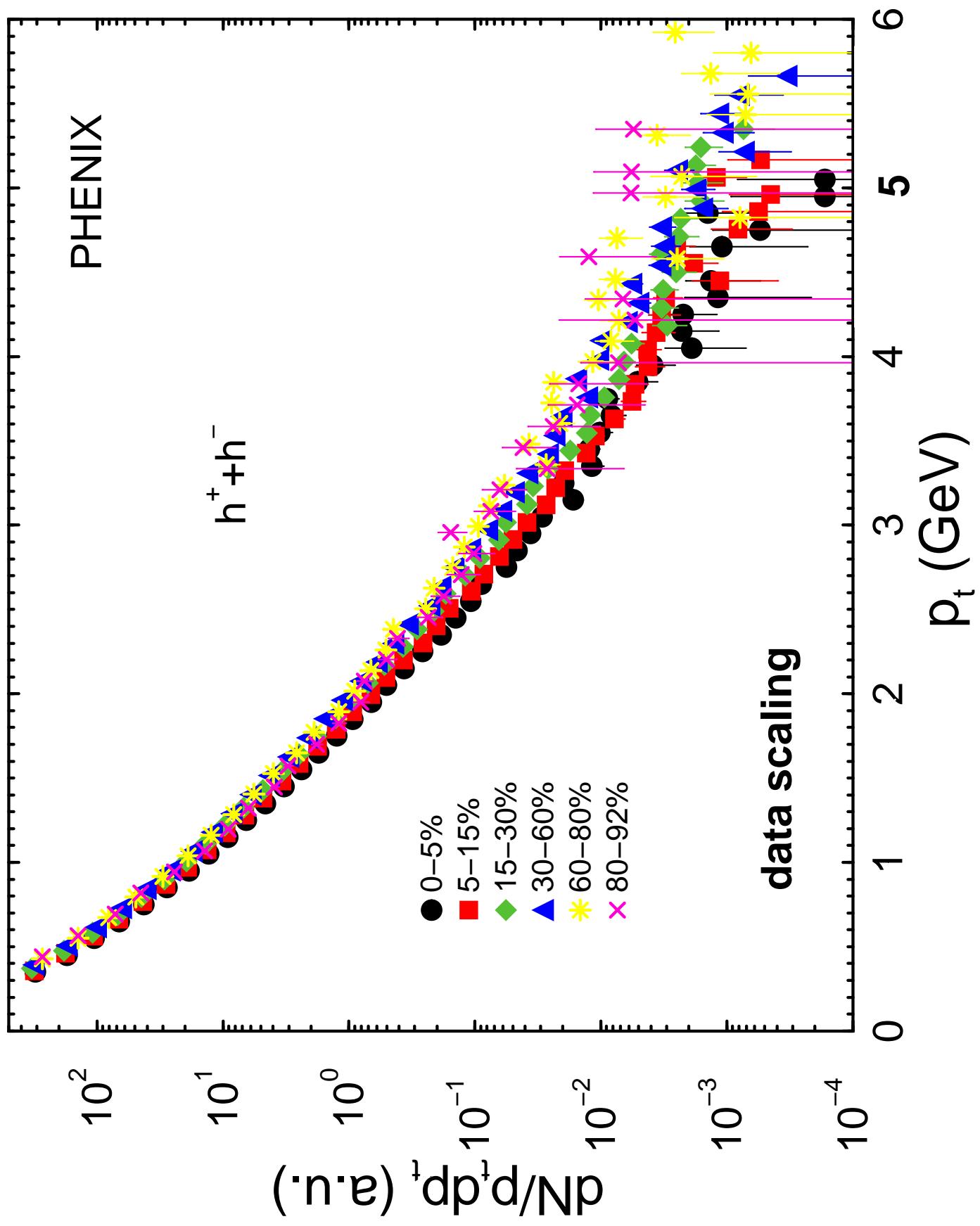
Scaling in transverse momentum



$$p_{\text{scaling}}^2(\text{fit}) \sim \frac{1}{N_{\text{part}}} \frac{dN}{d\eta} \sim \ln(Q_s^2/\Lambda^2)$$

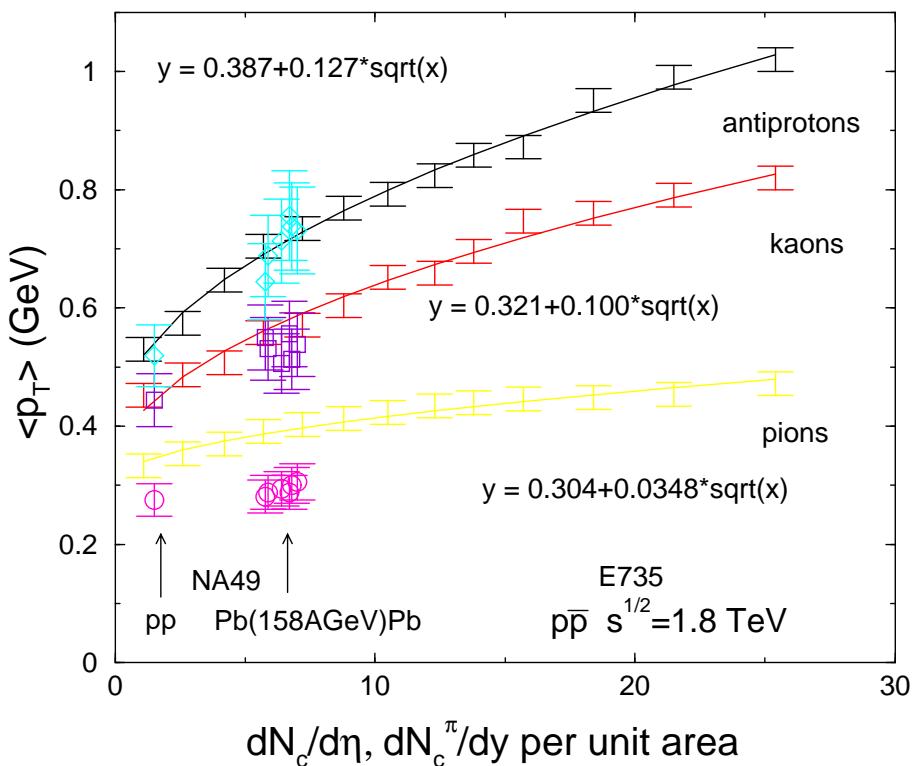
(last relation from Kharzeev and Nardi, PLB 507 (2001) 121))

now: take $\sigma \sim N_{\text{part}}$ and $dN/d\eta$ from data and rescale!



Identified Hadrons

Scaling relation $\langle p_t \rangle \sim \sqrt{\frac{1}{N_{\text{part}}} \frac{dN_c}{d\eta}}$ should also work for π , K , \bar{p} , ... in pp and AA?



✓ works for identified hadrons, too!

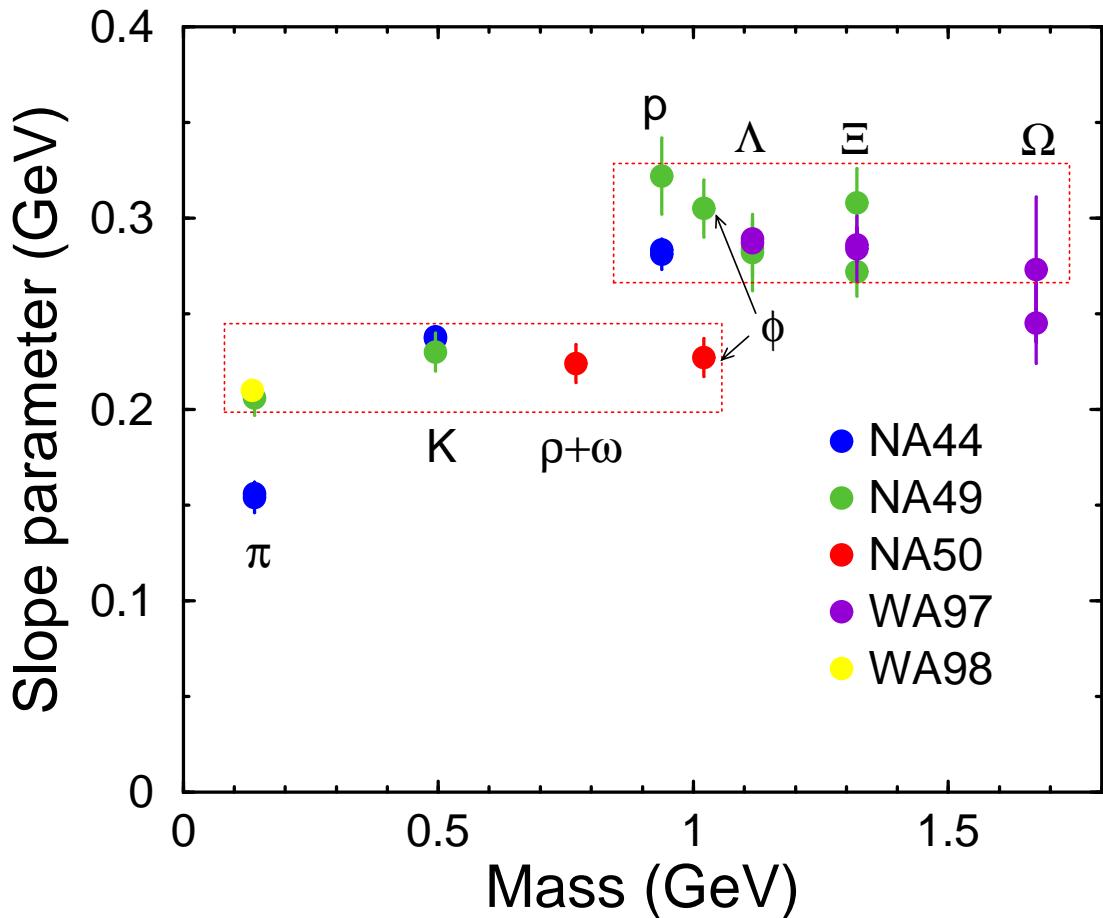
? but different slopes for different particles

→ intrinsic p_t broadening in $p\bar{p}$!

AA: mean p_t is of similar magnitude as in $p\bar{p}$!?!

Where is the flow?

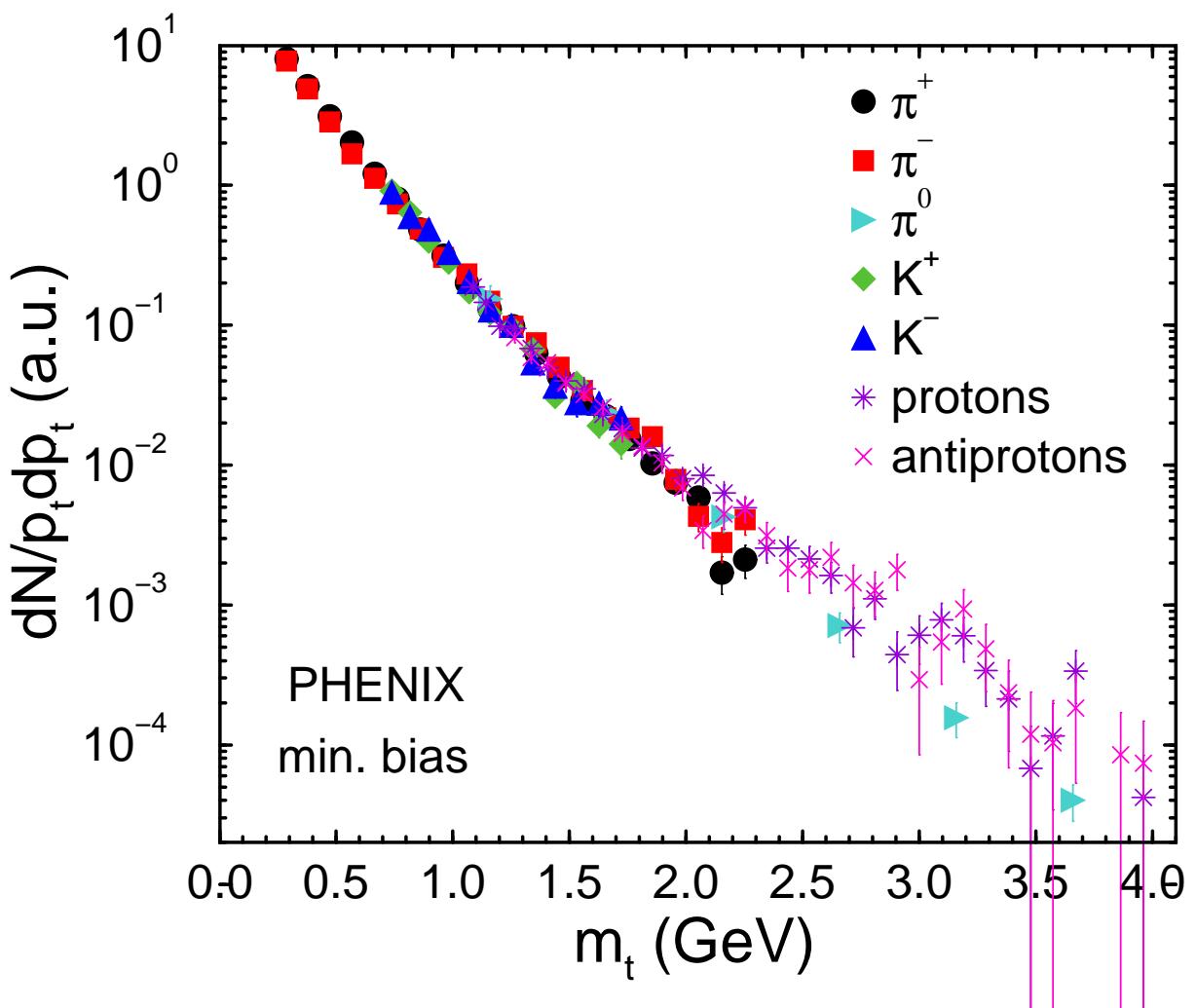
Slope parameters for PbPb at SPS



1. flow of hadrons: $T_{\text{slope}} = T_0 + \beta^2 \cdot m_{\text{vac}}$
2. flow of quarks and quark coalescence:
$$T_{\text{slope}}(\text{baryons}) = 3/2 \cdot T_{\text{slope}}(\text{mesons})$$
3. generalized m_t -scaling?

Generalized scaling for identified hadrons

$$\frac{dN}{dy dm_t^2} \sim \sigma \times f\left(\frac{m_t}{p_{\text{scaling}}}\right)$$



→ same local slope at given m_t !

Local slope parameter:

Assume the scaling function to be a power law:

$$f\left(\frac{m_t}{p_{\text{scaling}}}\right) \sim \left(1 + \frac{m_t}{p_{\text{scaling}}}\right)^{-n}$$

and define the local slope as

$$-\frac{1}{T_{\text{slope}}} = \frac{d}{dm_t} \ln(f(m_t/p_{\text{scaling}}))$$

$$T_{\text{slope}} = \frac{p_{\text{scaling}}}{n} + \frac{1}{n} m_{\text{vac}}$$

\implies looks like hadronic flow formula!

$p\bar{p}$ (interpolated): $n = 12.26$, $p_{\text{scaling}} = 1.68$ GeV

STAR: $n = 13.65 \pm 0.42$, $p_{\text{scaling}} = 2.74 \pm 0.11$ GeV

Consequences for centrality dependence:

$$\frac{1}{\sigma} \cdot \frac{dN}{dy} \sim \int_{m_{\text{vac}}}^{\infty} f\left(\frac{m_t}{p_{\text{scaling}}}\right) dm_t^2$$

$$\frac{1}{\sigma} \cdot \frac{dN}{dy} \sim p_{\text{scaling}}^2 \cdot F(m_{\text{vac}}/p_{\text{scaling}})$$

- particle numbers increase as:

$$\frac{1}{N_{\text{part}}} \frac{dN}{dy} \sim p_{\text{scaling}}^2 \sim < p_t >^2$$

- particle ratios increase for more central collisions as p_{scaling} increases like:

$$\frac{K}{\pi} < \frac{\bar{p}}{\pi} < \frac{\Lambda}{\pi} < \dots$$

(for the power law parameters we find increases from pp to AuAu of $K/\pi : \bar{p}/\pi : \bar{\Lambda}/\pi = 1.5 : 2.2 : 2.7$)

New Paradigm

Initial stage: the color-glass condensate

- initial quark-gluon phase **saturation**
- intrinsic p_t **broadening**
- **scaling** with saturation momentum and system size

Hadronization stage: the explosion

- **explosion** due to the condensate of the Polyakov loop

[Dumitru and Pisarski, hep-ph/0102020]

- self-similar: **scaling** relations survive
- self-critical, chaotic: **power law** distributions